DAM DEVELOPMENT IN INDIA

From Ancient to Modern Time

INCOLD
Indian Committee
on Large Dams

Central Board Of
Irrigation & Power

ICOLD 2024

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Front Cover Photo
Top: Second Century Kallaini dam, an International heritage structure, still in operation

Bottom: Srisailam dam, a modern marvel

Back Cover Photo
Sardar Sarovar, a mega multi-purpose landmark dam

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FOREWORD

India is among the foremost countries in the world to utilise its water resources and lay the foundations of dam development. Dam construction in the subcontinent began about five thousand years ago. The ingenuity of the dams and waterworks structures developed in the past are proof of the hydraulics wisdom in the history of India. The traditional knowledge systems of development and management of water resources has survived in India from pre-historic to contemporary time. Across this vast subcontinent, numerous dams of various types and sizes have been built at different geographic locations, over different periods of time. Many of these remarkable dams standout as technological marvels internationally and some of the old structures rank among globally historic dams that are still in operation.

Presently, with its rich heritage, India is a leading dam-building nation that incorporates most modern science of engineering and design in large dam construction. Several world-class large multi-purpose dams with storage facilities along with some hydropower projects are being built in India. At present time, the nation ranks third after China and the USA in terms of number of dams. As we enter an era defined by complex challenges, including climate change, population growth and heightened demands for water resources, the importance of sustainable dam development, in safeguarding our future, becomes increasingly significant.

The International Commission on Large Dams (ICOLD) is holding its 92nd Annual Meeting & Symposium from 29th September to 3rd October, 2024 in New Delhi. On such occasions, it is customary for the host country to bring out special publications on dams, which form an important component in illustrating the dam development in the country: It was decided, therefore, to bring out this important publication, to acquaint professionals about the rich heritage of dam building in India.

This book presents the chronology of dam development in India. It traces the evolution of dam building in the subcontinent, spanning across different eras - from Ancient to Modern times. It illustrates the knowledge of hydraulics that prevailed in the ancient time and portrays the engineering marvels built in India through centuries. The activities during the different periods are elaborated that highlight the country as a leading dam-building nation.

To capture the history of dam development spanning more than 5000 years is not an easy task and I wish to compliment the members of the 'Publication Committee', for the dedicated efforts made by them in bringing out this valuable book.

I trust that the book will be of immense interest to professionals and individuals throughout the world, who are involved in the field of dam development.

R.K. VISHNOI

President INCOLD &
Chairman & Managing Director,
THDC India Ltd. Rishikesh

PREFACE

Historically, India has been a dam building nation - This is the culmination of achievements through ages by successive regimes, with their knowledge of hydraulics, foresightedness and dedicated professionalism. In India, dam construction has been one of the oldest engineering practices from the time immemorial to harness water resources for irrigation, drinking and other needs.

India is credited with a long history of human intervention in the management of water due to its typical climatic conditions of intense monsoons followed by prolonged droughts. Irrigation of cultivable land has been practiced in India for many centuries. Ancient scriptures give insight into the traditional water storage and conservation systems prevailing in the past. Historical evidence reveals that dam building works in the Indian subcontinent began about five thousand years ago, in 3rd millennium BC. The Kallanai dam (2nd Century AD) is considered to be the fourth oldest dam in the world which is still in use.

Medieval planners and hydraulic engineers had the benefit of the knowledge system already established in the field of water harvesting. Traditional dams and big earthen embankments appear to have been designed with knowledge of hydraulics. Earthen as well as masonry dams were constructed in very large numbers from 2nd century to 17th century AD. Many of these are functioning even at present. The advances in design of high masonry dams brought to India by the British engineers had added to the construction technology and boosted dam development. During the Colonial period beginning 1800 AD, the British played a major role in numerous dam constructions. As construction of dams continued with increasing water needs, development in the design and types of these dams evolved. Large dams with storage reservoirs began to appear especially after the introduction of concrete in construction.

From the beginning of the Post-Independence period in 1947, numerous dams of varied types and sizes have been built for the purpose of irrigation, water supply, hydropower development, flood control and other purposes. Remarkable development has been made in dam building during the last several decades. A number of world-class large multi-purpose dams with storage facilities and hydropower projects are being built in India and some of the dams are considered globally outstanding, based on their merits. Moreover, safety of the dams being important, the Government of India has taken due steps in this direction, including rehabilitation of the old structures as well.

As per the records of the National Register of Dams, India has 6138 large dams in operation today, with another 143 under construction. As the demand for water is steadily increasing with the economic and demographic growth, India continues to construct world-class large dams, involving state-of-the-art tools and technology, keeping in consideration the safety and sustainability concerns. Number of large multipurpose dams, including mega hydroelectric projects are being built in India, and in future, in meeting growing needs and mitigating the adversities of climate changes, the legacy of building world-class large dams will continue.

This book portrays five thousand years of dam development practices in India: It traces the evolution of dam building engineering, stretching across the different eras and documents, the involvement of successive regimes in dam development across space and time. It covers the chronology of dam development in India, spanning over - Ancient, Medieval, Colonial and Post-Independence periods, encompassing the Modern era and the foreseeable future scenario.

ADIYTA K. DINKAR

Secretary General, INCOLD & Secretary
Central Board of Irrigation & Power, New Delhi

CONVERSION FACTORS

India adopted the 'metric system' of weights and measures since 1958. For some centuries prior to that, during the British Colonial time, the 'British system' was in use. In the present document which spans the history of dam encompassing several centuries, most of the past records were not in the 'metric system' now in use. Attempt has been made to present most data after conversion to 'metric units', but in some cases of data taken from the past records, it became necessary to present the details in the system originally used.

Conversion factors from 'British system' to 'metric system':

Length

1 m =100 cm = 3.2808 ft

1 km = 1000 m = 0.6214 mile

1 mile = 1.6093 km

Area

1 sq.m =10.764 sq.ft

1 ha = 10000 sq.m = 2.4711 acres

1 acre = 0.4047 ha

1 sq.mile = 640 acres = 2.59 sq.km = 259 ha

Volume

1 cubic metre = 35.315 cubic feet

1 acre feet = 1233.48 cubic meters

1 ha.m = 8.1 acre feet

1 cubic km = 1 BCM = 1000 MCM = 810713 acre feet

1 TMC = 28.317 Million cubic meters

1 M acre feet = 1.233 cubic km = 43.56 TMC

Rate of flow

1 cubic metre/sec = 1 cumec = 35.315 cusec = 22.82 MGD

TIME PERIOD

This book covers the chronology of dam development activity in India, encompassing the following broad periods:

Pre-3000 BC to 550 AD: Ancient Period including Pre-historical time

550 AD to 1800 AD: Medieval Period including Late Medieval times

1800 AD to 1947 AD: Colonial Period under the British

1947 AD to the Present: Post-Independence Period and Modern Time

ABBREVIATIONS

TE : Earth

ER : Rockfill

PG : Gravity/Masonry

I : Irrigation

H : Hydel

C : Flood control

S : Water supply

N : Navigation

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PROLOGUE

Dams are structures designed by humans to impound water and modify its flow downstream. From antiquity, dams have provided mankind with critical infrastructure, as humans have endeavored to efficiently exploit the natural resources to aid supply of water for irrigation and domestic needs, towards sustenance of civilization. The practice of dam building, in the concept of water harvesting, has always been considered as a basic requirement to harmonize the natural hydrological regime with the human needs. Dams have served to ensure adequate supply of water by storing in times of surplus and releasing it in times of scarcity, thus also mitigating floods and making significant contribution to the management of the finite water resources. As civilizations have matured, dam infrastructures have been further developed for power generation towards industrial growth, domestic utility and various other services. The scientific achievements in the field of hydraulics of large-scale dams have a very long history. In thousands of years of dam development, millions of dams of various types have been beneficially constructed worldwide.

India is credited with having a long history of human intervention in the management of water because of the distinctive climatic binary conditions of intense monsoons followed by prolonged droughts. Rainfall is confined to a few months of the year and that too uncertain, erratic and uneven. Thus, historically making Indian agriculture dependent heavily on irrigation. Hydraulic wisdom in India has historical footprint of several millenniums. The need to efficiently harness water for irrigation and domestic utility, propelled the growth of hydraulic science and development of waterworks. Dams appear to have been developed through ages, with knowledge and understanding of dam engineering and the hydrological processes, for harvesting and maneuvering the vagaries of nature.

Dam construction in this land began about five thousand years ago, during pre-historic time. Information about the growth of knowledge of science of hydraulics in building dams in India since ancient time have been uncovered by historical research. Ancient scriptures and evidences from archeological investigations in the contemporary time suggest the likelihood that - this land may have been the birthplace of 'the art of dam building'.

Since long, people understood the pragmatic utilization of water resources, compelled by necessity of existence. The ingenuity of the dams and waterworks structures developed in the past are proof of the hydraulics wisdom in early history of India. The traditional knowledge systems of development and management of water resources has survived in this country from pre-historic to contemporary time. Numerous dams of various types and sizes have been built at different geographic locations, over different periods of time, across this vast subcontinent. Of these, several remarkable dams standout as technological marvels internationally and some of the old structures rank among globally historic dams that are still in operation. Study revealed that the dams appear to have been designed not only with a sophisticated knowledge of dam engineering but also with an understanding of the principles of basin water balance. Insights into such dams, relevant to their apparent characteristics of durability, adaptability to the environment, that exemplify sustainability, provide valuable guidance for the future developments.

While the early dam developers relied more on proven experience and empiricism, besides their knowledge of hydraulics as well as understanding of the principles of basin water balance, the art of building dams transformed with advancements in construction materials and rational design methods. In the late 19th century and during the 20th century, developments in the related scientific domains, brought significant changes. As construction of dams continued to progress with demographic growth, variants in types of dams evolved. Large dams began to appear especially after the introduction of concrete in construction. Advances were made by taking a more three dimensional approach to dam designing. Introduction of soil & rock mechanics and numerical methods, resulted in further enhancement in dam engineering.

In the modern time, dams are being built in a planned manner, adopting state-of-the-art technology. The advent of new technologies has boosted the dam construction activity in the country. Several world-class large multi-purpose dams with storage facilities, and hydropower projects are being built in this nation and some of the dams are considered globally outstanding, based on their merits.

With its rich heritage, India is among the foremost dam-building nations that incorporate most modern science of engineering and design in large dam construction. At present time, this nation ranks third after China and the USA in terms of number of dams. This is the culmination of achievements dating back millennia. According to the National Register of Large Dams, India has 6138 large dams in operation today, with another 143 under construction.

With the steadily increasing demand for water resources and dam development, as consequence of economic growth and rising population, this nation continues to establish large dams, adopting modern technology and innovations in design and construction methodology. The Indian government has been actively promoting the development of large multipurpose dams, including mega hydroelectric schemes in national interest.

As we enter an era defined by complex challenges, including climate change, population growth, and heightened demands on water resources, the importance of dams in safeguarding the future becomes increasingly significant. In foreseeable future, in meeting the growing needs in various sectors, the rhythm of building safe and sustainable multipurpose large dams will continue in this nation, in keeping with the ICOLD vision: *"Better Dams for a Better World"*.

This book titled, *'History of Dam Development in India'*, embodies the five thousand years of dam building history of this nation, tracing its evolution and the accomplishments across space and time. It covers the chronology of dam development in India, elaborating the building activities spanning over - Ancient, Mediaeval, Colonial and Post-Independence periods, and encompassing the Modern era and the foreseeable future scenario.

As we embark on an enthralling journey through time and explore deeper into the realm of dam building in this subcontinent, many fascinating dimensions of the early scientific endeavours emerge. While navigating through the annals of history we realize that: The past legacies are the underpinning of the achievements in dam engineering in the modern time.

EPILOGUE

Information about the knowledge of hydraulics in building dams in ancient India has been uncovered through archaeological explorations and research. In the Indian subcontinent, dams have been built since antiquity, driven by the necessities of water harvesting for irrigation and domestic needs, to sustain civilization. Evidence has revealed the enriched knowledge of waterworks management and dam building that existed in the past. Studies have provided insight into the hydrological wisdom of the civilization since prehistoric times.

By exploring the past, fascinating dimensions of the accomplishments in dam-building activity in ancient times have emerged. Dam-building in the Indian subcontinent dates back to the beginning of the 3rd millennium BC. The Gabarband (dam) tradition of water management is an unsurpassed marvel of civilization in prehistoric times. In the 3rd and 2nd centuries BC, discoveries at the Harappan site at Dholavira provided evidence of a unique hydraulic network and stone dams built for water harvesting, which was their legacy. The number of dams discovered at the Buddhist monastic site at Sanchi (3rd to 2nd century BC) with surplus flow arrangement and flood protection capabilities, display the knowledge of irrigation and water-work development that prevailed in early times. Excavations at Inamgaon in Maharashtra, a Chalcolithic settlement dating from 1400-1000 BC, have brought to light an extensive stone rubble and mud embankment for impounding water. Rock edicts of Junagarh in Gujarat and ruins provide evidence of one of India's oldest dams that created Lake Sudarsana, an outstanding work of the Maurya dynasty (335-320 BC). The Kallanai Dam, constructed by the Chola King Karikala in the 2nd century AD, still in operation, provides insight into the hydrological wisdom of the past in sustainable dam building.

Until systematic studies were undertaken in contemporary times to uncover the past, much of the information about ancient dam-building feats would have remained unknown. Indeed, the planners and dam developers in later periods benefited from the knowledge system already established in the field of water harvesting and dam building in ancient times in the Indian subcontinent.

EPILOGUE

In Medieval period, irrigation is said to have been one of the major reasons for the growth and expansion of Empires in India. As agricultural development was the pillar of the economy, hydraulics and waterworks were paid special attention, as irrigation was seen to be a catalyst for enhanced agricultural production. This is demonstrated by the fact that all stable empires, regional kings and local communities paid attention to irrigation and waterworks development. The other compelling reason for building water harvesting structure was due to repeated droughts that had often caused famines. The construction of the dam had brought extended areas under controlled cultivation that sustained a large population and elevated prosperity.

In Medieval India, farming was in a way 'hydro-agriculture' with a strong role for village communities. Traditional society had a significant technical sophistication towards water management. The inscriptions, literary sources and the archaeological data emphasize technical competence in building dams and embankments. During the period, numerous dams of various sizes and types were built. Some of the notable dams of the period are engineering marvels, by global standards. The structures were designed using indigenous wisdom and constructed with the generous support of native rulers and chieftains over centuries. A number of these dams are operational even at present time. These structures have withstood the test of time and survived over several centuries, and proven themselves to be environmentally sustainable. These exemplify the technological innovations developed by the society, in the past, to accommodate their primary needs. They demonstrate the level of knowledge in dam engineering that prevailed and exhibit the water harvesting skills developed in this country towards social sustenance and prosperity by adapting to the distinctive Indian climate and maneuvering the vagaries of nature.

The scale of development of numerous dams and related waterworks in India, before the advent of the British, gives an idea of the vastness of the system across the subcontinent and it can be stated that anything comparable of it did not exist in other parts of the world in that period.

It is worth mentioning, in this context, that the traditional technical skill in building earthen as well as masonry weirs - perfected over time, had won the admiration of British officials, which is documented in their writings later in the 19th century AD. As an example, Sir Arthur Cotton, the celebrated British engineer, in his writing in 1874, had noted that:

"While the British had been cautious about laying a foundation in shifting sand for the Ganges Canal, the natives had proceeded with boldness and engineering talent to build weirs. These were built in sandy beds of rivers without any rock or sound stratum to found them on...."

In fact, adds Cotton, *"the natives have constructed tens of thousands of tank in almost every kind of soil with earthen dams without the puddle bank which English engineers have fancied necessary... ..."*

EPILOGUE

With the advent of Colonial era, the story of irrigation waterworks transformed in this country. This phase is often referred to as the beginning of the epoch of 'modern hydraulics'. In the British period, there emerged a centralized system of irrigation management with bureaucratic structure. Broad changes in the administrative background gave fillip to development projects. British Colonialism initiated a radical break in both technique and hydraulic principle by introducing perennial irrigation systems in several parts of the subcontinent. In the beginning of the 19th century began irrigation development with the renovation, improvement and extension of existing canals and waterworks. After studying the Indian practice of irrigation, the British ventured on new major works. Permanent headworks in the form of dams/weirs were built across rivers. By flattening the river's variable flow regime, irrigation, in effect, was transformed from seasonal to perennial possibility - towards sustainable development. Number of dams constructed by the British engineers in the country during the Colonial period incorporated intricate canal networks.

Initially, the British dam practice was dominated by the adoption of earthen embankments with puddle clay cores. Later, the British engineers, benefitting from the advanced academic trainings, entered upon the domain of building large masonry dams. The real contribution to dam engineering was in the construction of masonry dams with advance hydraulic arrangements. Dams of higher heights and storage capacities were built during the Colonial time. The British constructed high dams with an idea of developing storage reservoirs so that the stored water could be utilised even during droughts and in flood mitigation. The methodology of dam construction changed from coursed rubble masonry on the exposed faces to cement concrete construction. Emergence of new technology and inventions enhanced the efficiency of dam building and led towards scientific development of large masonry dams in the country. Long-term dynamics of these facilities is credible.

Till the time the Union Jack was lowered in 1947, British engineers had constructed some of the most advanced dams and irrigation waterworks in the country. The advances in design of high masonry dams were initiated in this country in the period and the legacy continued. In fact, a few of the initial large dam projects of independent India were envisaged during the Colonial period. Colonial irrigation in India, in a way, demonstrated that State, in alliance with science of engineering, can possibly tame the rivers for sustainable water harvesting. This ideology survived until the end of the Empire and influenced the water management vision in the Post-Colonial Independent India.

EPILOGUE

After Partition of the country, over half of the area irrigated by the British government waterworks in undivided India ended up in Pakistan. The slow pace of irrigation development during the last decades of Colonial regime had also aggravated the problem. Accordingly, to make the nation self-sufficient in food production and make it economically self-reliant, the first Prime Minister of Independent India campaigned for dam development in the country. Irrigation was made mostly a state subject. A series of Soviet-style Five Year Plans opened up new avenues in large multipurpose dam development, with renewed emphasis on bringing more areas under irrigation. Colonial legacy, in many ways, reinforced the pursuit of hydraulic capitalism through large dams.

Progressively, after the Bhakra, enormous dams became the order of the day. The 20th Century and thereafter witnessed the establishment of several irrigation and multipurpose large dams in India. One of the potent solutions to the multi-faceted challenges, due to steep rise in population, demand for food, water and power, as well as flood mitigation, has been the creation of water storage facilities. Construction of hydropower storage dams has been a major component of investment in water management in the country.

Right from Independence, India has been developing at a fast pace. The country is placed amongst the most progressive dam-building nations that incorporate modern science of engineering. And the zeal for large dam construction continued, as the nation embarked on a modern phase of development.

As this country shifts towards cleaner energy sources and the demand for energy rises, hydropower, especially pumped storage, is gaining significant traction, particularly for enhancing system flexibility: Recent Government of India policy initiatives and guidelines for pumped storage plants are expected to invigorate the sector in the coming years.

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